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WATERSHED MANAGEMENT RESEARCH

ENGELMANN SPRUCE-SUBALPINE FIR, LODGEPOLE PINE, AND ASPEN FOREST TYPES

at the

FORT COLLINS RESEARCH CENTER

Rocky Mountain Forest and Range Experiment Station

(A Project Analysis and Working Plan)

by

B. C. Goodell

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INTRODUCTION

The forest types of Engelmann spruce-subalpine fir, lodgepole pine, and aspen comprise the subalpine zone of vegetation lying, roughly, between the elevations of 8- and 12-thousand feet.

The distribution of this zone within the boundary of the Fort Collins Research Center is shown in Figure 1. In area, it is approximately 14.5 million acres. Although no accurate figures are yet available on areas of the individual forest types, they may be estimated as follows:

Engelmann spruce-subalpine fir	7.0	million	acres
Lodgepole pine	5.5	"	"
Aspen	2.0	"	"
Total	14.5 1/	"	"

On any given watershed, all three forest types are likely to be found (Figure 2). On north and east slopes, the spruce-fir type usually extends throughout the elevational range of the zone. On south slopes, lodgepole pine may cover the complete range of elevation.

1/ These areas represent total forest land. The areas of commercial forest are much less (Tables 5 and 6 of T.R.R.).

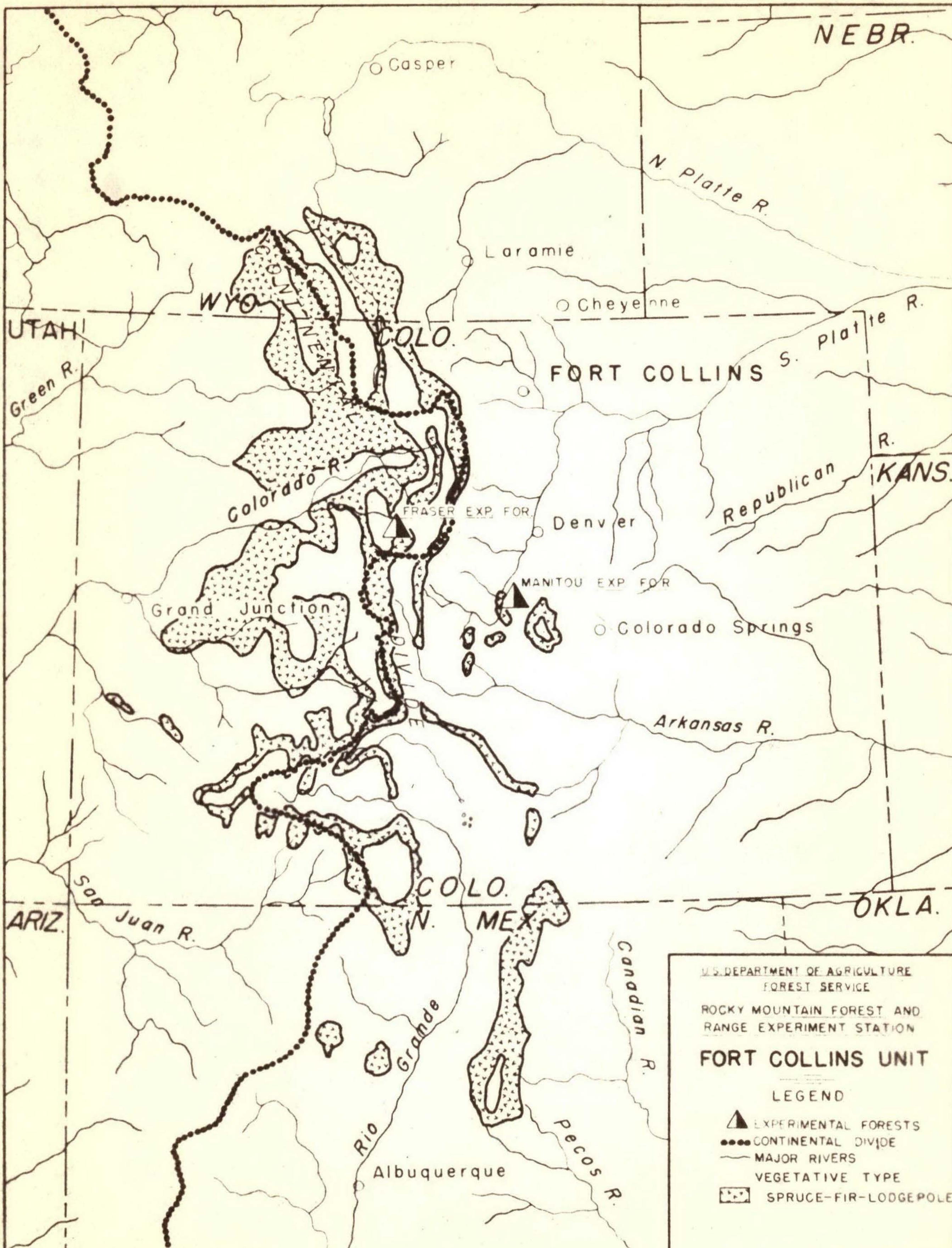


Figure 1.--Distribution of Engelmann spruce-subalpine fir, lodgepole pine and aspen forest types.

Map #5

Figure 2.--Forest types of Engelmann spruce-subalpine fir, lodgepole pine and aspen on same watershed.

Aspen may occur on any aspect, but is limited to elevations below 10,500 feet. In general, it appears to be a persistent type only on exceptionally wet areas and where recurrent snow slides wipe out the coniferous species that depend on reproduction from seed (Figure 3).

The spruce-fir and lodgepole pine forests of the subalpine zone are characterized by high density. This is particularly true of the spruce-fir type where a closed, high canopy is normally supplemented by a partial understory (Figure 4). It is less true in the lodgepole type. Here, the overstory commonly has a closed canopy, but an understory is usually lacking (Figure 5). By its lack of winter foliage, aspen itself presents quite a different picture from the viewpoint of watershed management. However, aspen stands often contain an understory of spruce, fir, or pine, so even the winter canopy may still be appreciable.

The topography of the subalpine zone is rugged, with steep slopes and many narrow, V-shaped valleys (Figure 6). This gives rise to great micro-climatic variations associated with solar radiation differences. This can be illustrated by the fact that at this latitude, a 70-degree south-facing slope receives, during spring and summer, the same intensity of sunlight as does a horizontal surface at the equator, and the possible hours of sunshine are the same. Over the same period, a similar but north-facing slope, receives sunlight at the same intensity as a horizontal surface in northern Alaska and for much less of each day.

Figure 3.--Aspen at beginning of snow melt period.

Figure 4.--Engelmann spruce-subalpine fir type with characteristic understory.

Figure 5.--Lodgepole pine type with characteristic understory.

Figure 6.--Steep-sided, narrow valleys are common.

The soils of the zone are varied in origin. The greater portion of parent bedrocks consist of granites, gneisses, schists and igneous rocks. Glaciation has left its mark in numerous moraines. Flood plains of coarse gravel and cobbles are common along lower reaches of the streams.

Regardless of origin, it is characteristic of the soils that they are coarse in texture and porous. Weathering is slow at these high elevations and, thus, the proportion of clay is low while that of gravel is high. Soil materials (regolith) are usually deep, allowing deep water penetration and storage (Figure 7). Abundant litter prevails, but on south slopes is often thin, with mineral soil spottily exposed.

Perhaps of greater significance are the differences found in soils developed on north and south exposures at the same elevation. These differences will materially affect the hydrologic and silvicultural aspects of a management program.

Soils on north exposures (Figure 8) are developed under a spruce-fir stand. The surface is protected by a dense litter layer consisting of moss, lichens, and dead twigs and needles. Vaccinium grows dense and vigorous. Below the litter layer occurs a light gray, dusty, bleached layer 2 to 6 inches thick. Beneath the gray layer is a light yellowish brown layer 8 to 15 inches thick, characteristic of the spruce-fir type. Both these horizons are acid. A third layer 12 to 18 inches thick next occurs, olive-gray and brown-steaked in color, cemented by silt and clay particles on the faces of small rocks and in small soil pockets. Following this

Figure 7.--Soil materials are often deep over bed rock, allowing for deep water storage.

Figure 8.--Soil developed from schist on a north exposure under a stand of spruce and fir.

layer is the parent soil material of varying thickness, grayish in color, loose and open with occasional large rocks.

In contrast are the soils of south exposures developed under lodgepole pine (Figure 9). The surface is protected by a thin litter layer consisting of needles, twigs, and cones, and a sparse growth of vaccinium. Beneath the litter layer may or may not occur a thin, gray, acid layer seldom over 3 inches thick, if present. Following this is a brown layer 4 to 12 inches thick, loose and friable, and grading into the parent soil material. The latter is of varying thickness, olive-gray in color, and consisting of angular fragments of gravel with little fine material, but with considerable coarse sand.

The two soils discussed above are distinctly different and will react differently under the same type of management. The soils of north exposures are podsolized brown forest soils, while those of the south exposures are brown forest soils. One exhibits a profile development, the other does not. Both differ hydrologically in moisture retention and in internal drainage.

Another important soil occurring in the spruce-fir, lodgepole pine, aspen type is the one developed on glacial till (Fig. 10). This soil will have the same profile characteristics as those discussed previously when the glacial till occurs under a stand of lodgepole on the one hand and a stand of spruce-fir on the other. In both instances soils developed from glacial till will have greater internal drainage, considerably less moisture retention, and little susceptibility to erosion under timber harvesting and road building. The nature of

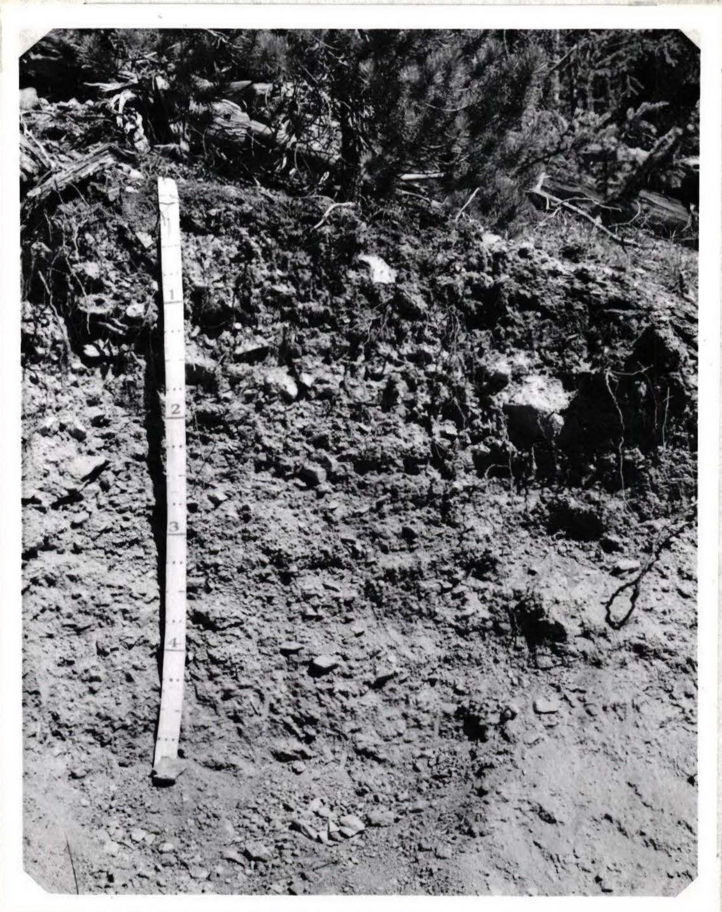


Figure 9.--Soil developed from schist on a south exposure under a stand of lodgepole pine.

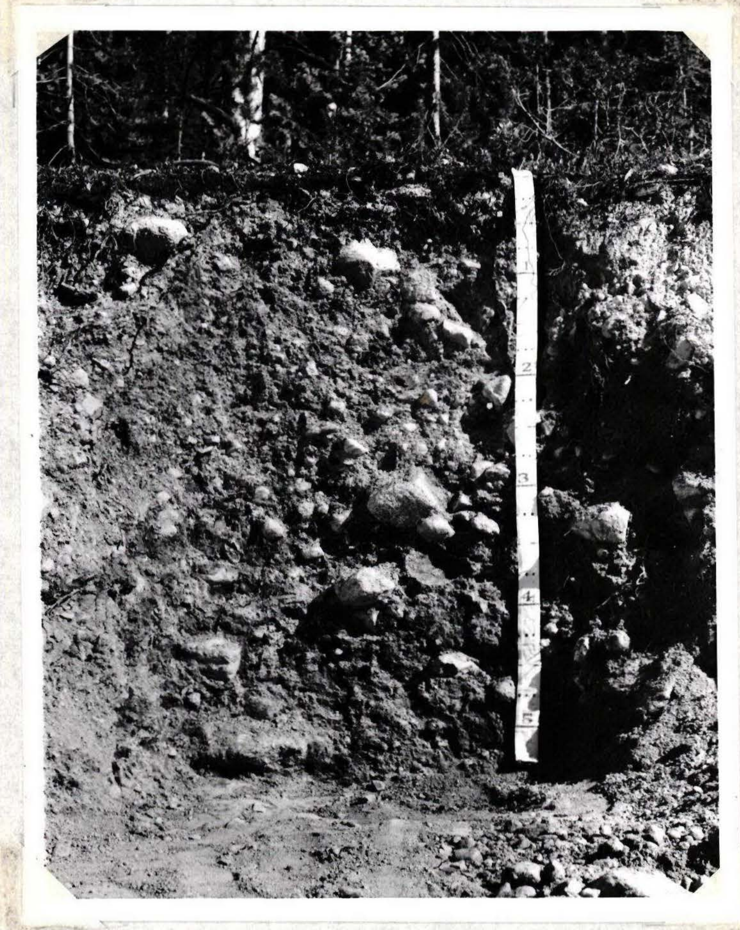


Figure 10.--Soil developed from glacial till. Profile characteristics depend upon the forest stand growing on it.

the parent soil materials which consist of many rounded rocks and boulders and coarse soil particles, make this soil one of the most stable of the mountain soils.

Infiltration capacity is generally more than adequate to allow absorption of incident rainfall and snowmelt water, and the soils are stable against erosion. Erosive surface runoff seldom occurs, even where logging has caused disturbance.

Water yields from the subalpine zone are high in spite of a dry climate. At 42 stations within the elevational range 8- to 12-thousand feet, the annual precipitation has averaged 19.6 inches. Although it is fairly certain that the actual average is in excess of this amount, since weather stations are usually located near towns in valley bottoms, the true value is probably not over 25 to 30 inches.

Streamflow from the subalpine zone averages 12 area-inches per year (Fig. 11), or about half of the annual precipitation. This high yield in relation to precipitation is caused by the prevailing low temperatures and the fact that a large part of the precipitation falls during winter and spring when vegetation is dormant. At 20 weather stations, the mean annual air temperature has averaged 36.8°F. The monthly distribution of precipitation is indicated in Table 1 by the 46-year record at Fraser, Colorado, where the elevation is 8,500 feet.

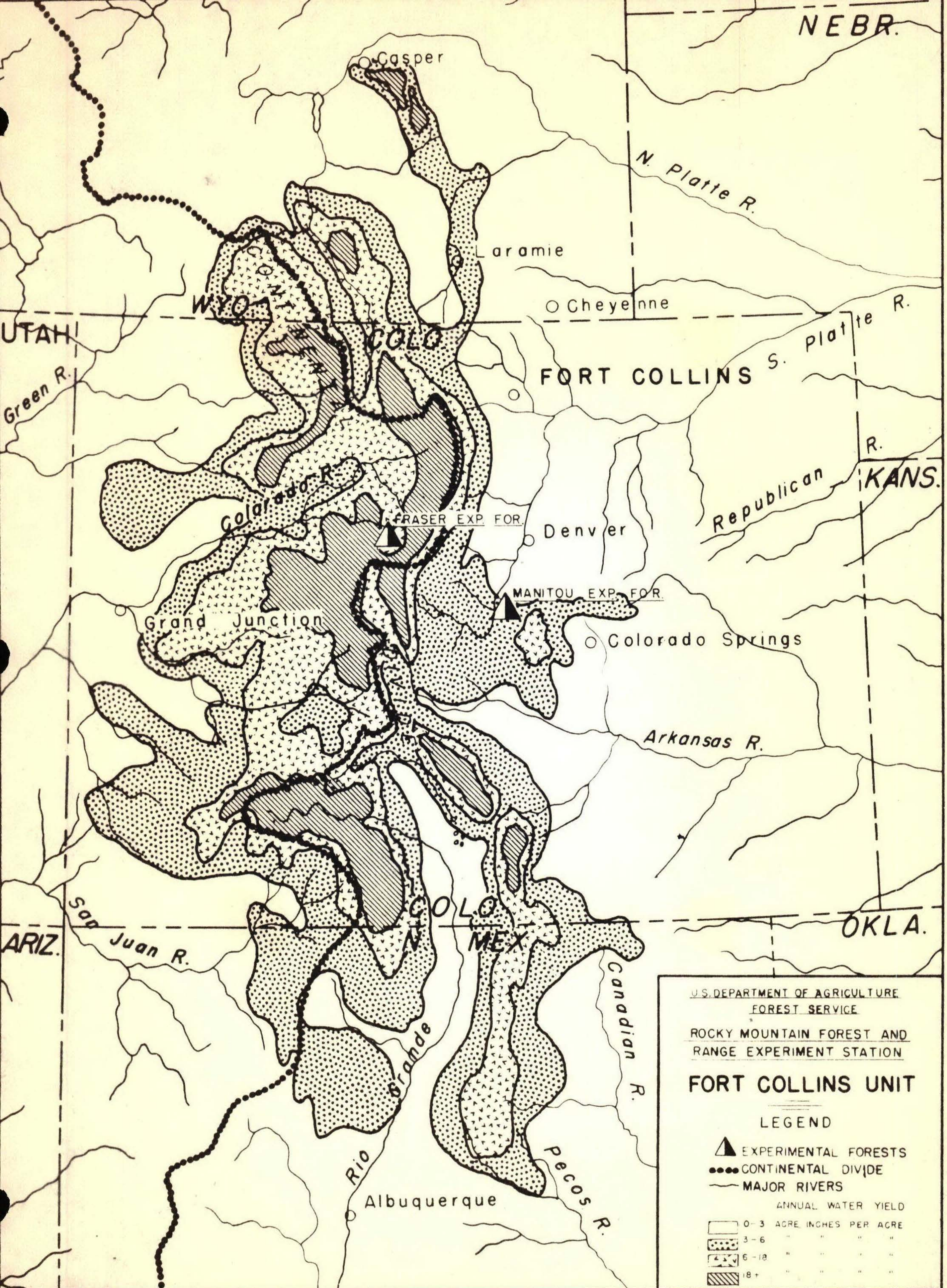


Figure 11.--Annual water yield.

Map #7

Table 1.--Distribution of precipitation by months at Fraser, Colorado.

January	1.49	July	2.09
February	1.60	August	1.64
March	1.70	September	1.33
April	2.06	October	1.28
May	1.71	November	1.17
June	1.37	December	1.29
	Total: 18.73		

Characteristically, both rainstorms and snowstorms are low in intensity, short in duration, but frequent. Figure 12 shows that over an 8-year period on the Fraser Experimental Forest, 78 percent of all rainstorms produced less than 0.3 inches of precipitation each. During this period, the greatest rainstorm of record produced only 0.77 of an inch. The greatest intensity was 2.5 inches per hour, but this storm produced less than 0.5 inches of rain. While these data are from one station only, they are probably indicative of rainstorm activity over the subalpine area. There is some evidence that intensities, as well as amounts of rainfall, increase with elevation, but pertinent data are few.

Snowstorms are similar in character to rainstorms. Most storms deposit less than 6 inches of snow and a storm leaving over 12 inches is a rarity in the subalpine zone. The falling snow is usually dry and low in density; wet snows are almost entirely restricted to late

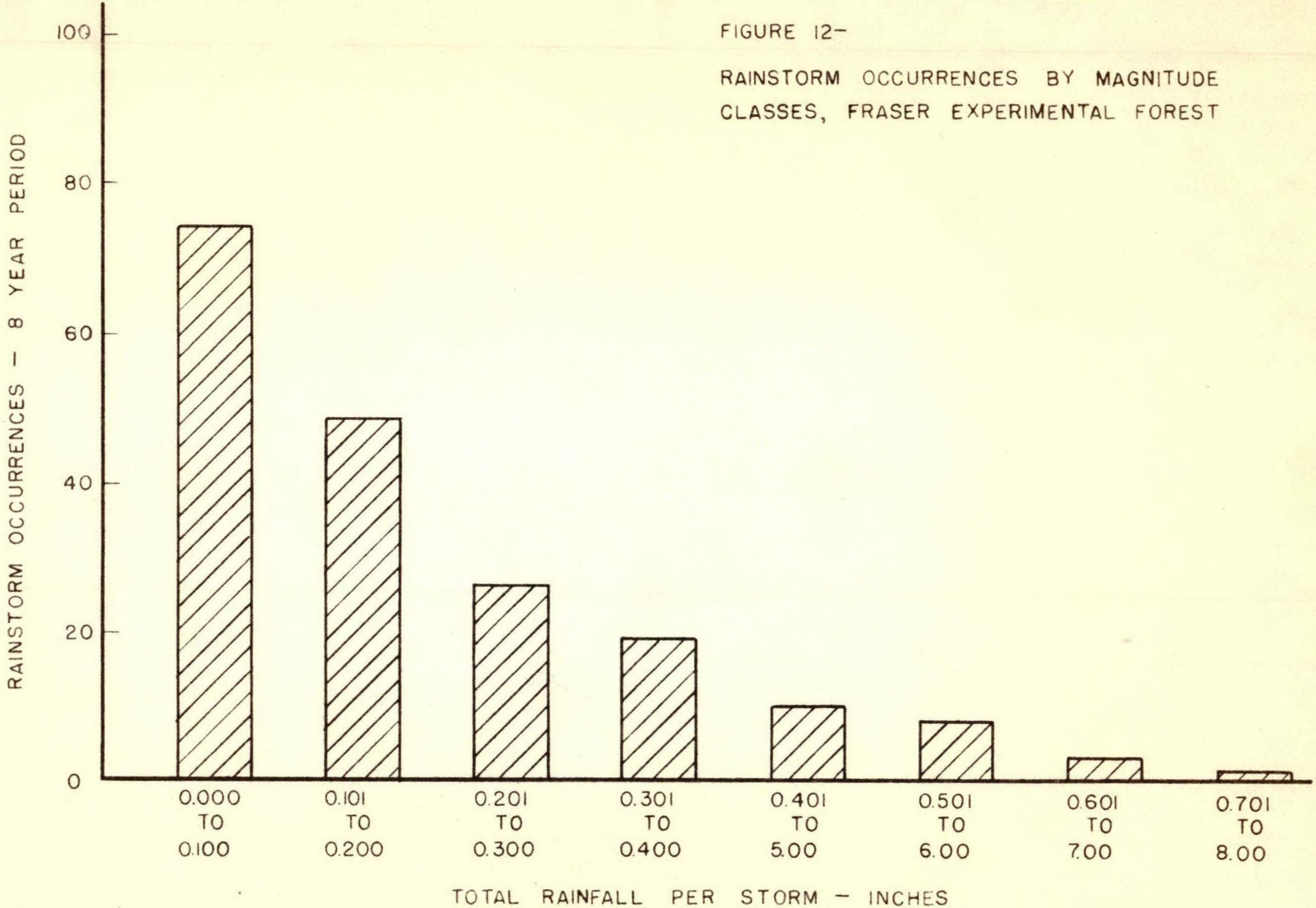


FIGURE 12-

RAINSTORM OCCURRENCES BY MAGNITUDE CLASSES, FRASER EXPERIMENTAL FOREST

spring. The dry snow readily clings to tree crowns, however, and often remains for several days (Figs. 13 and 14).

Storms in both winter and spring are characteristically separated by periods of clear, dry weather. During these periods, the relative humidity is usually low, often below 10 percent, even in winter. The combination of frequent storms, interception of snow on tree crowns, and intervening periods of clear, dry weather favors evaporation loss. Restricting such loss are prevailing low temperatures.

Most streamflow originates from snow which forms from 50-75 percent of the annual precipitation. Because snow is subject to little transpiration loss and low rates of evaporation, it accounts for from 75-90 percent of annual streamflow. Because snow melts slowly and soils are porous, surface runoff is minor in amount. Maximum rates of snowmelt probably yield no more than one inch of water per day, and this is readily absorbed by the soil. Thus, streamflow from snowmelt, even at its spring peak, is the result of ground water discharge (Fig. 15).

Snow usually begins to occur in September of each year and rains do not become the prevalent form of precipitation until the following June. From October to April the snow accumulates; melting being only common on south-facing slopes. Thus, the bulk of winter precipitation is held in storage until released by spring warmth during the months of April, May, and June.

Snowmelt in the subalpine appears to be caused mainly by direct solar radiation and such radiation absorbed and re-radiated by trees. A lysimeter study in California (3) showed that 85.4 percent of the

Figure 13.--Intercepted snow immediately following end of storm.

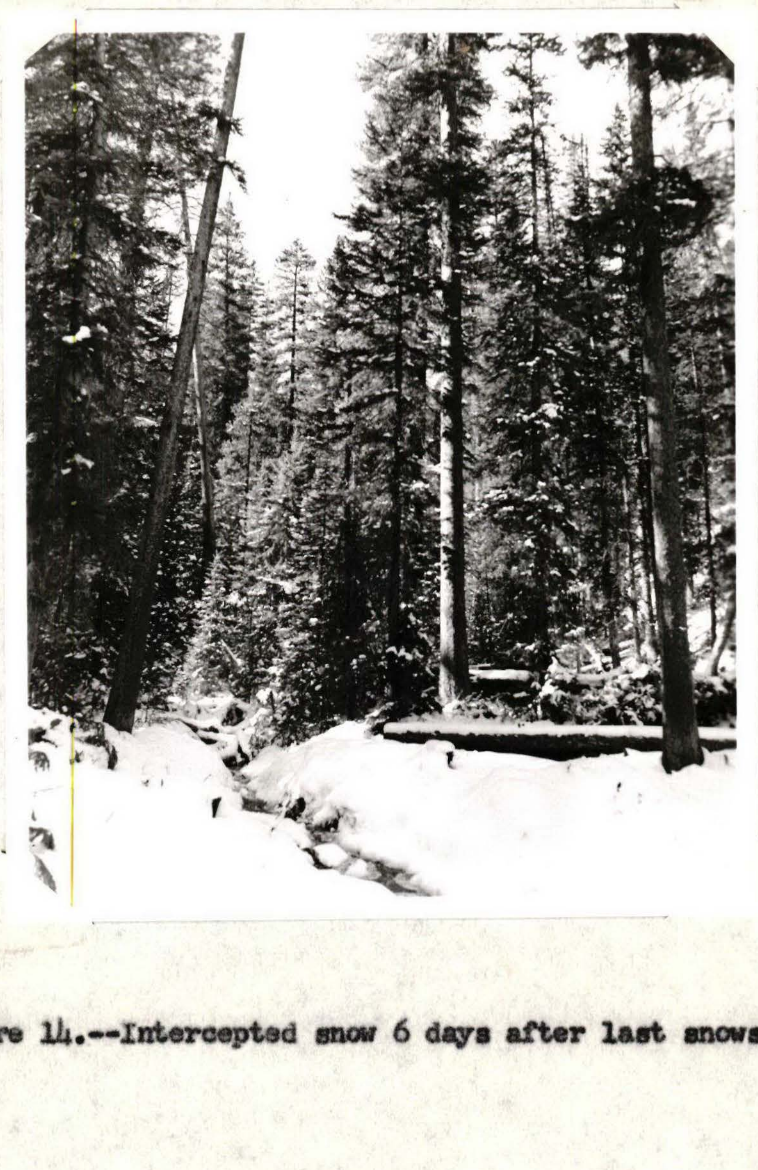


Figure 14.--Intercepted snow 6 days after last snowstorm.

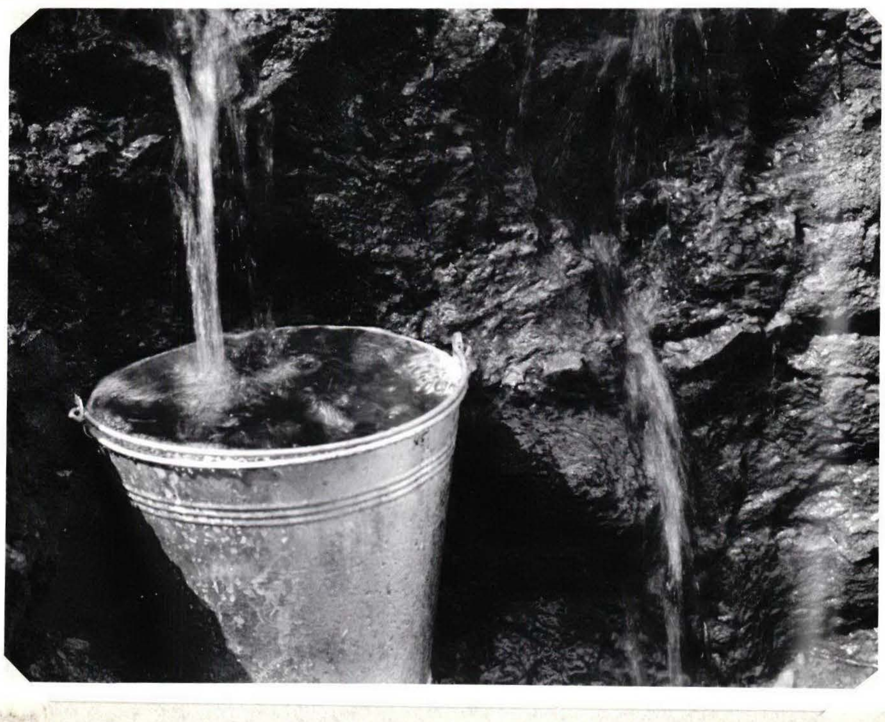


Figure 15.--Ground water flow from snow melt.

total melt was so-caused, 13.1 percent by convection, and 1.5 percent by condensation. In the drier climate of Colorado, it is probable that the proportion of radiation-caused melt is even higher. On south slopes, particularly those that are steep, this radiation is sufficiently intense to cause melting during winter months. On other slopes, melting sufficient to cause loss of water from the snowpack seldom, if ever, takes place until early spring (Figs. 16 and 17).

As a result of the time distribution of melt, streams remain low during fall and winter, and rise rapidly from early or late April to a peak in June. Following the peak, they drop rapidly at first, then more slowly to a definite flattening out of the hydrograph in August. Summer rains have little direct effect on streamflow because of drafts by transpiration and evaporation, although those of late summer influence the runoff of the following spring by partially priming the soil. Thus, streamflow stays low through late summer and drops slowly by the depletion of ground water through fall and winter to the start of the next spring thaw. Typically, 50 percent of the annual streamflow is discharged in a 30-50 day period late in spring and early summer. A typical hydrograph is shown in Fig. 18; the monthly distribution in Fig. 19.

IMPORTANCE OF AREA TO WATER SUPPLIES

Situated as it is on the higher slopes of the mountains, the subalpine zone forms a vast source of water to the semi-arid lands encompassing it at lower elevations. The estimated water production from Colorado is 17.5 million feet. The subalpine zone is estimated to produce 1 acre-foot per acre, 14.5 million acre-feet, or nearly 85 percent of the total water supply.

Figure 16.--Remnants of winter snow on south facing slope, May 10, 1949.

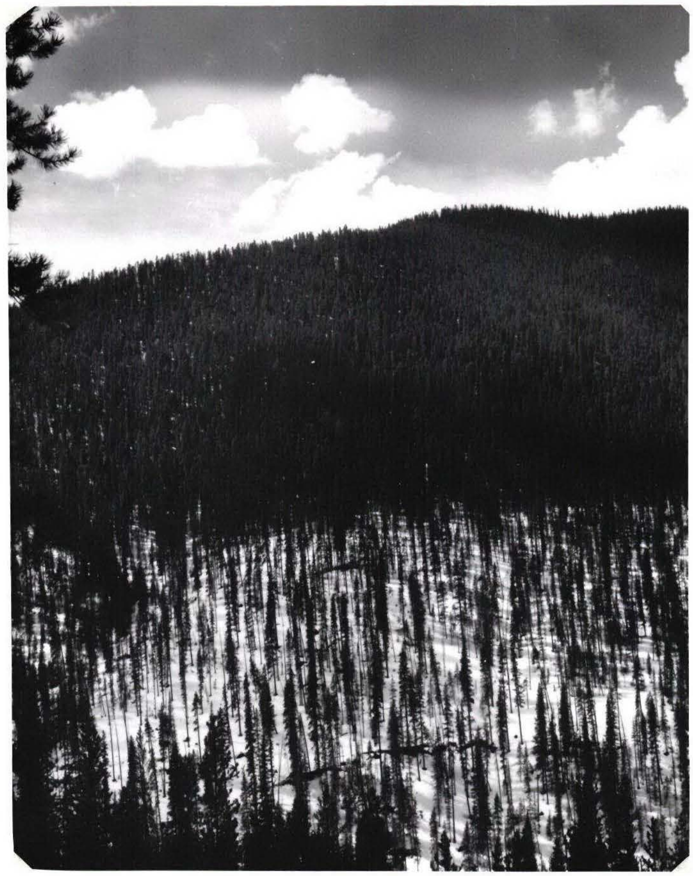


Figure 17.--Unbroken snow cover on north facing slope across valley from site of Figure 16, May 10, 1949.

FIGURE 18-
AN AVERAGE STREAM HYDROGRAPH, FOOL CREEK, FRASER EXP. FOREST

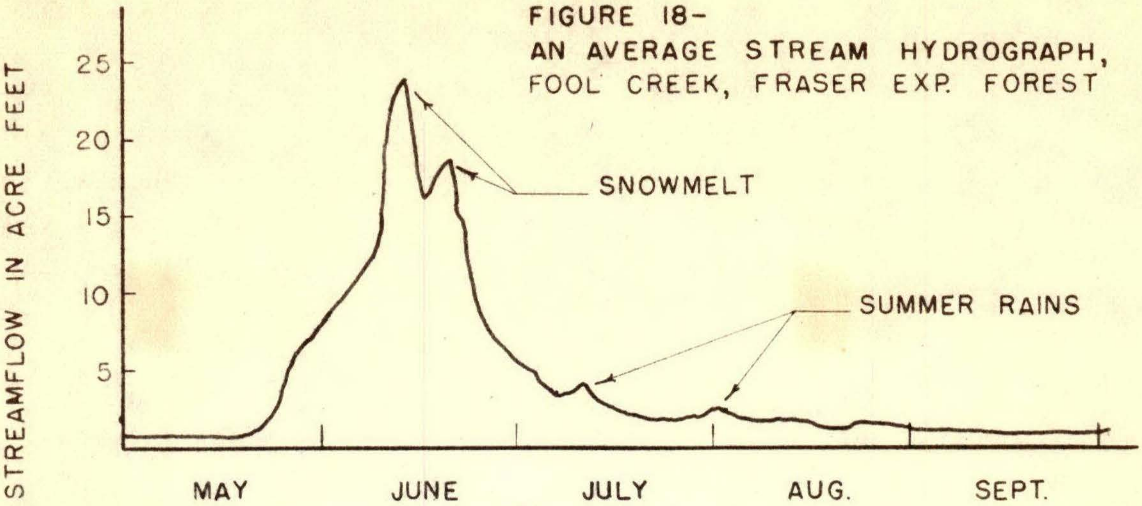
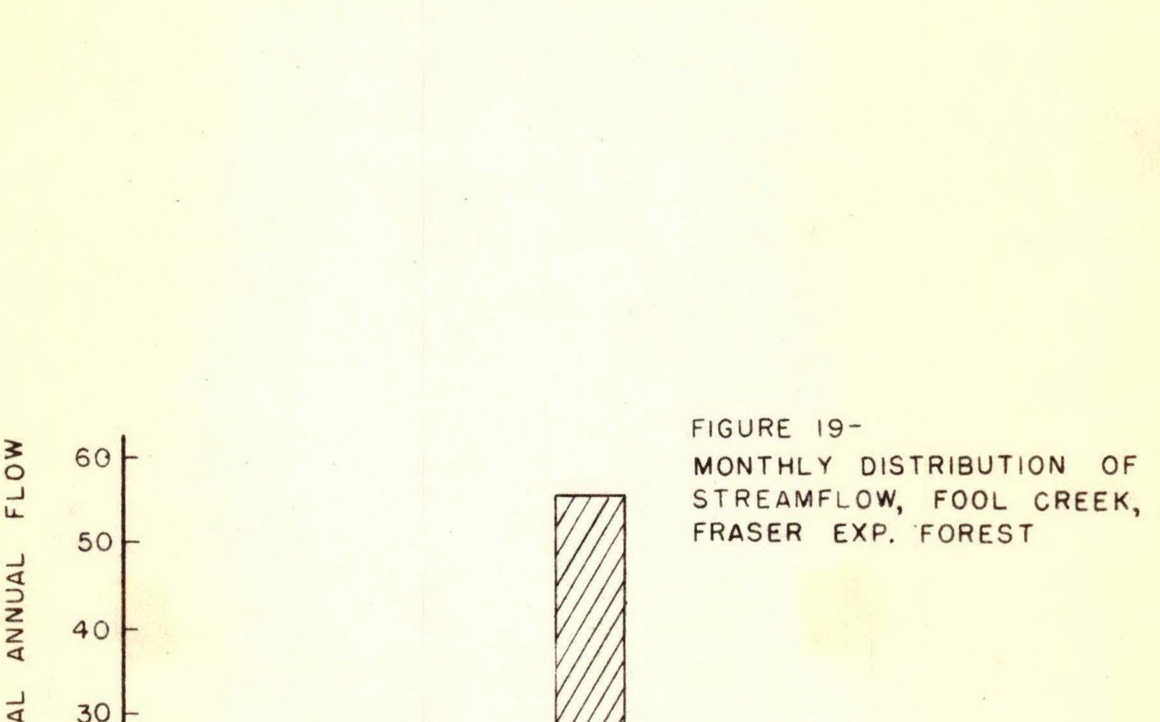


FIGURE 19-
MONTHLY DISTRIBUTION OF STREAMFLOW, FOOL CREEK, FRASER EXP. FOREST



Since water in large quantities is essential to modern economy, its value may be appraised in terms of the civilization itself in the dependent area. It is estimated that 1/3 of the water originating within Colorado is used within the state, while 2/3 leaves the state and is used elsewhere. The population of Colorado is 1.5 million. It thus may be said that 3 times this number, or 4.5 million people, are dependent on the water originating in the Colorado mountains. If 85 percent of this water comes from the subalpine zone, then the water resource of this area may be said to have value equal to that of the livelihood of near 4 million people.

Generally, current supplies of water do not equal the demand. If supplies cannot be increased, curtailment of water use now considered essential, or even restriction in the population growth of the Rocky Mountain region and Southwest, seems inevitable. It is with this perspective that watershed management research in the subalpine zone is viewed.

Aside from the value of the water resource for domestic use, irrigation, industrial processes, and power production, it has value in providing recreation. Lakes and streams provide fishing, boating, swimming, besides simple esthetic enjoyment. Water in the form of snow provides skiing for many thousands of persons annually (Fig. 20).

The seasonal distribution of streamflow also has economic importance. Normally, annual water yield from the subalpine zone is heavily concentrated in late spring and early summer. The concentration is less pronounced in the case of larger watersheds, but is still strong. This concentration contrasts with a July or August

Figure 20.--Recreational use of the water resource.

peak of demand for water for irrigation and domestic purposes. Any shift at all in the time distribution of water yield in the direction of synchronization between peak supply and peak demand would be generally of economic benefit. Any flattening of the peak of yield, even if attained through a higher proportion of flow prior to the peak, would also be of benefit in some cases where canals, tunnels, and storage facilities are taxed by the peak flow. Thus, any ability to control the time distribution of yield would have economic benefit. However, the greatest would undoubtedly come through ability to delay the peak and increase the proportion of post-peak flow.

PAST WORK

Research to date has shown that water supplies can be increased through forest management. Within the Rocky Mountains the first study to show this effect conclusively was that conducted by the Forest Service and Weather Bureau at Wagon Wheel Gap from 1910 to 1926 (1). In this study was measured the effect on streamflow of clear-cutting a thin stand of aspen, Douglas-fir, and Engelmann spruce from a 200-acre watershed (Fig. 21). Comparison with a similar control watershed revealed that the timber removal caused an average increase of 16 percent in annual streamflow over a 7-year period following logging. The increase was greatest in spring periods, but extended through the summer months. The authors attributed the streamflow gain to a reduction in the interception of snow and its subsequent evaporation.

Figure 21.--Wagon Wheel Gap watersheds 30 years after treatment of right-hand watershed.

A more recent study of a watershed was that which compared the flow from the Elk and White Rivers of western Colorado before and after the killing of timber by insects on one watershed (9). Indicated was that an increase in runoff of 22 percent resulted from the timber killing, which affected only some 30 percent of the watershed.

Preliminary results are now available from the Fool Creek-East St. Louis Creek study of the Fraser Experimental Forest. By late fall of 1955, clear-cutting was completed on 229 acres, or 32 percent of the 714-acre Fool Creek watershed. This clearing included 35 acres for roadways and 194 acres by logging. A stripwise pattern was used in logging, with the cutting of all live timber 4 inches d.b.h. and larger from alternate strips. Four widths of strip were used: 1-, 2-, 3-, and 6-chains. Strip length is approximately 600 feet of slope distance (Fig. 22).

Although the area cut by the end of 1955 comprised only 80 percent of the initial, planned logging treatment and was re-continued in the summer of 1956, preliminary analyses were made to determine if the partial treatment showed an effect on the 1956 streamflow.

The analyses showed a highly significant increase in streamflow for the available period of record, May 3 - October 12. The indicated increase was 37 percent, 4.20 area-inches, or 250 acre-feet. The data from this one year further suggested that the timber removal caused earlier snowmelt and stream rise, a higher peak, but also greater summer flow.

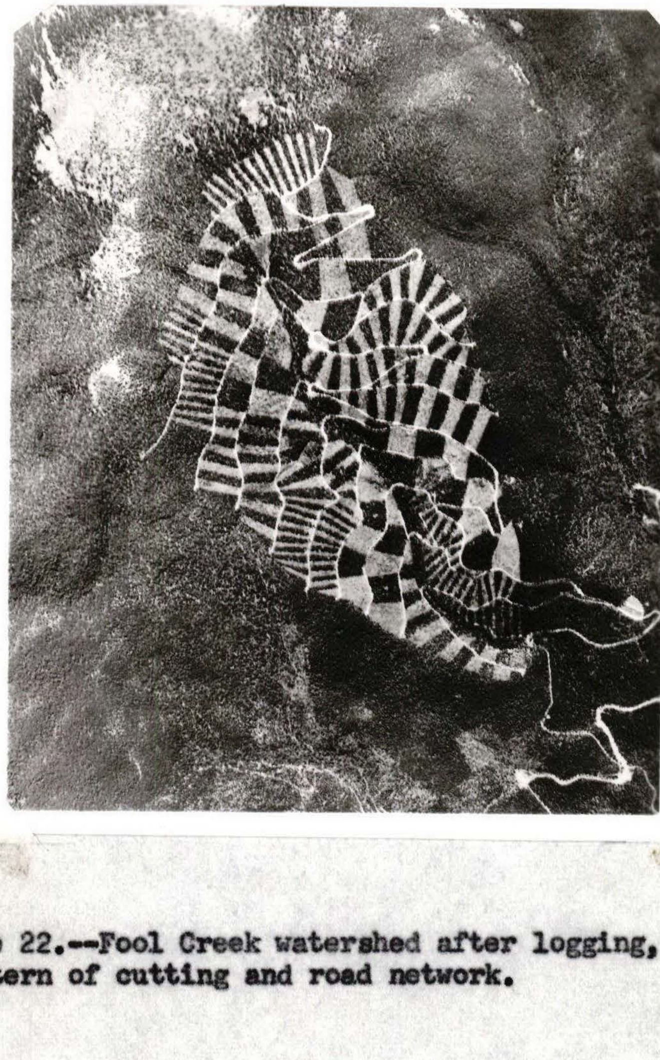


Figure 22.--Fool Creek watershed after logging, showing pattern of cutting and road network.

These watershed studies have demonstrated that the harvesting of timber can increase supplies of usable water. In each case, water yield was augmented without appreciable increase in erosion. However, the question of why forest harvesting has the observed effects is still unresolved. It seems obvious that the higher spring flow results largely from increases in the snow accumulation. However, it may be partly caused by less evapo-transpiration from the soil during the preceding late summer and fall. The greater summer flow may be caused by three factors: greater ground water recharge in spring, reduced interception of summer rain, and reduced soil moisture draft.

Many plot studies and a few of the lysimeter variety have been made in an attempt to explain the causes of greater water yield. Although helpful, these have failed to account for the apparent magnitude of the effects. Several studies made on the Fraser Experimental Forest from 1938 to 1949 indicated that the interception of snow with the favoring of subsequent sublimation and evaporation was a major cause of snow loss. The removal of nearly all timber from plots in mature lodgepole pine was observed to increase the amount of snow reaching the ground by 29 percent, and rainfall on the ground by 35 percent (13). In the same study, soil sampling to 18 inches revealed no effect by timber cutting on evapo-transpiration losses from the soil. Because these latter data included the influence of timber cutting on rainfall interception, it was apparent that rainfall interception was a negligible factor in the water available for streamflow. The conclusion was that benefit of timber

harvesting to water yields would result solely or mainly from the reduction in the interception of snow.

Other studies in mature spruce-fir forest (10) and in 35-year-old lodgepole pine (5) gave similar results and strengthened the above conclusion. The latter study included sampling for soil moisture to depths of 4 feet, but still there were no significant differences in late summer soil moisture between the dense, control plots and those heavily thinned. However, in spite of intense sampling, 12 samples on .27 acre plots, the sampling error was sufficiently high to mask differences as great as 2 inches of water.

Snow studies made elsewhere have led to similar conclusions regarding the importance of snow interception (7, 12). On the other hand, watershed studies at the Coweeta Hydrologic Laboratory (6, 8), where snow is of little consequence, have given conclusions that forest removal is chiefly effective on streamflow through the reduction of the evapo-transpiration loss from soil moisture.

That evapo-transpiration losses from soil moisture must be considered in explaining the effects of forest harvesting from snowy as well as snowfree watersheds is indicated by the watershed study results given previously. The streamflow effect of cutting tree growth from the Wagon Wheel Gap watershed decreased rather rapidly in 7 years following the cutting. During this period, the re-growth of aspen was rapid, but that of coniferous species negligible. Because snow interception by aspen is necessarily zero, or nearly so, the decline cannot be attributed to a renewal of interception loss. Aspen re-growth with its increase in transpiration can explain the decline in streamflow.

Both the Elk-White River study and the Fool and East St. Louis Creeks experiment show effects too great to be explained by past observations on plots of the effect of timber harvesting on snow accumulation. The 1956 results from the Fool Creek study indicate that water yield was increased 15.5 area-inches from the area actually cleared of timber. However, snow surveys made in April 1956, before the beginning of snowmelt, showed an average difference of only 4.1 inches of water equivalent between the snow in uncut and cut strips.

In the Elk-White River study (9), the increase in yield per acre of timber killed by insects was 7.7 area-inches. This, again, is greater than would be predicted from snow interception measurements taken at Fraser.

Most existing evidence indicates that, while increasing water yields, timber cutting adversely affects its seasonal distribution in some respects. However, there are some reasons for conjecture that forest manipulation might also be used to benefit seasonal distribution. The three watershed studies previously referred to demonstrated early stream rise and higher annual peak resulting from timber harvesting. However, higher summer flow was also revealed.

More rapid snowmelt resulting from reducing forest density has been shown by plot studies made on the Fraser Experimental Forest (5, 13). Forests shade snow from direct sunlight and thus reduction in its density may be expected to increase rates of melt. However,

Miller (11) has pointed out that forests are effective absorbers of solar radiation and that part of the absorbed energy is re-radiated in long wave lengths to the snow surface where it is more readily absorbed than is the short wave-length energy of direct sunlight. Miller (11) also refers to the effect of forest litter in reducing the albedo of the snow surface and so favoring the absorption of radiation (Fig. 23). These forest effects lead to thinking that, under some circumstances, forests might be managed to reduce melt rates.

Under conditions where forest cutting increases melt rates, this fact might be used to reduce the flood peak from a watershed. Evidence from other studies on the Fraser Experimental Forest (2, 4) suggests that a given watershed produces its annual peak flow at the time when the area yielding water is at a maximum. From the St. Louis Creek watershed, the annual peak was observed to come when only 42 percent of the watershed was still snow-covered. Supposedly at this time, lower areas with southern aspect had ceased to yield appreciable water and after this date the non-yielding area increased more rapidly than new areas came into production. This leads to the hypothesis that the peak might be reduced by cutting a lower elevation forest in such fashion that snow disappearance would be advanced and these areas would become non-yielding at an earlier date. Earlier flow would be realized and the pre-peak flow increased, but the peak might be decreased.

PROBLEMS

Watershed management research is concerned with the disposition of precipitation after it reaches the level of the forest canopy in

Figure 23.--Lodgepole pine litter reducing albedo of snow.

its path to the ground. There is no evidence that forests quantitatively affect precipitation, only that they influence its disposition once it enters the physical confines of the forest. Forests affect total water yield by altering the proportion of precipitation that leaves a given area in the form of streamflow or groundwater as excess to evaporation and transpiration losses. Forests exert some control over this evapo-transpiration. By affecting snowmelt, forests also influence the seasonal distribution of streamflow.

Coarse, stable soils and low intensities of rainfall and snowmelt make erosion a minor problem, not justifying specific research. This leaves evapo-transpirational losses and snowmelt as the fields requiring watershed management research. Also needed, to supplement this research, is the acquisition of much more hydrologic information about the subalpine zone.

EVAPO-TRANSPIRATION

The manner by which forests affect evapo-transpirational loss, including snow sublimation, is varied. Rainfall interception, snowfall interception, evaporation and sublimation from the snowpack, evapo-transpiration of soil moisture are all affected phenomena.

Trees intercept rain and retain a portion until evaporated. They cause a net reduction in rainfall. However, if rainfall, reduced by interception or not, is entirely exhausted by evapo-transpiration from the soil, it can add nothing to streamflow. Observations at Fraser on plots have indicated this to be the case, but soil sampling, both in depth and intensity, may have been inadequate to reveal the true situation. Thus, the rainfall interception effects of forest

cutting on streamflow are still open to question. Since rainfall interception is reflected in soil moisture, the question can best be answered by studies of the latter.

It is well established that the water equivalent of the snowpack is inversely related to the density of the forest canopy overhead. However, there is some question whether this relation expresses an actual loss of snow of equal magnitude or whether some redistribution of snow is involved.

There are obvious reasons why a dense forest canopy may actually cause snow loss. Trees intercept snowfall and hold it favorably disposed to evaporation and sublimation in situ. Being exposed, in part at least, to more wind and solar energy, the rate of vapor loss from the tree-borne snow is probably greater than is the rate from snow on the ground. The intercepted snow presents more surface per unit mass than does the snowpack and its vaporization is thereby favored. Also, the intercepted snow is often re-dispersed by wind and while in transit to new deposition, must undergo much sublimation or evaporation. These are explanations but more analytical studies than have yet been made are necessary to establish their validity.

Forests undoubtedly affect the sublimation and evaporation of snow on the ground. Here, however, the influences are probably both positive and negative. Theforest decreases wind movement over the snowpack and so should decrease vapor loss. On the other hand, the temperature and thus the vapor pressure of snow under trees may be higher than that of snow in the open, during winter months when snow is not melting. Dense, continuous forests prevent the blowing of snow after it reaches the ground or pack surface. However, certain

patterns of timber suhh as long, narrow strips of timber alternating with similar cleared strips may favor movement from the snowpack by creating eddies and channeling wind. This movement may, in turn, cause vaporization. The net effect of these forest influences on vapor losses from the snowpack will not be known until further studies are made.

In the evapo-transpirational loss of soil moisture, transpiration is more important. It is a function of root depth and density, annual period of transpiration and depth of soil. In general, soil depth in the subalpine zone probably exceeds the rooting depths of the indigenous species. Thus, it is probably seldom a limiting factor. The rooting habits of the subalpine tree species are not well known. Neither are the periods of appreciable transpiration rate well known. Undoubtedly the evergreen species use some water throughout the year, but unknown is whether their winter use is appreciable. There is evidence that growing season use by aspen is considerably greater than such use by spruce, but the relative annual use is not known.

The evaporation of water from soil is a function of soil temperature, air vapor pressure and wind. Because soil temperature is lower under forest shade, air vapor pressure tends to be higher and wind speed less, evaporation is less under forest than in the open.

The net effect of forests is to cause evapo-transpiration from soil to exceed that in open areas. However, the magnitude of the difference requires study, as do the effects of forest type, density and age.

SNOWMELT

Observations on the relation of forests to snowmelt have led to conclusions that melt is retarded. Forests give shade from direct sunlight and, in this way, mitigate the effect of this most important cause of snowmelt. However, forests are also efficient absorbers of solar radiation and re-radiate to the snow in longer wave lengths which the snow absorbs to a much greater degree than it does direct sunlight. It thus seems possible that, under some circumstances, melting under forests may be more rapid than in the open. Open areas on steep, north slopes, for example, receive little, if any, sunlight during winter and early spring. Any sunlight that is received by the snow surface is incident at such a low angle as to deliver little energy per unit area. On the other hand, forests on such a slope present surfaces normal to the sun's rays and, thus, receive a full complement of energy. Much of this is converted to long-wave radiation, of which some will reach the snow surface and may cause melting. Studies may show that snowmelt rate can actually be decreased by forest manipulation on topographically shaded slopes. A reduction in forest litter by forest management may also act to reduce snowmelting by favoring a higher albedo.

If it is accepted at face value that reducing forest density always increases the rate of snowmelt, it is possible that peak streamflow may still be reduced by forest management. As discussed earlier, the speeding up of snowmelt at lower elevations may be

used to get more pre-peak flow and lower the peak.

Both total water yield and seasonal distribution are important to water users; the relative value depends on storage opportunities and costs. If storage facilities are ample, then total water yield may be of primary interest. Seasonal distribution becomes of dominant interest if storage is limited or non-existent. There is abundant evidence that forest management can favorably affect total yield. There is indirect evidence that it may also be used to control seasonal distribution to some degree. Much more research is prerequisite to the intelligent realization of either benefit.

The problems of watershed management in the subalpine zone may be summarized as follows:

1. How to minimize snow evaporation and sublimation.
2. How to minimize the evapo-transpirational loss of soil moisture.
3. How to control rates of snowmelt.

Research on these problems may show that management for maximum water values is incompatible with management for maximum timber and recreation values. If so, then a further problem will be to determine points of compromise.

OBJECTIVES OF PROGRAM

The primary objective of watershed research in the subalpine zone should be to get direct solutions to the problems listed above. These solutions should encompass the three forest types of the zone and the common range of aspects, slopes, soil depths, and types.

A secondary objective should be to learn how these solutions can be joined with silvicultural practices to derive the maximum total value from water, timber, and recreational opportunity. Since the relative importance of these three resources vary from watershed to watershed, the goal must be sufficient knowledge to enable flexibility in management methods.

To facilitate the most efficient attainment of these objectives and the application of results, greater general knowledge of the hydrologic characteristics of the subalpine zone is needed. Supplementary to the sparse observations now made, sampling should be done of annual precipitation, rainfall intensity, water yield, wind speed and direction, air temperature and air vapor pressure.

SPECIFIC STUDIES

1. Laboratory study of snow sublimation and evaporation: By wind tunnel tests and supplementary measurements of vapor pressure of snow, accurate equations will be derived relating sublimation and evaporation to causative factors of wind shear and vapor pressure differences.
2. Field study of snow sublimation and evaporation, and techniques of measurement: Measurements of wind, snow temperatures and air moisture under different conditions of forest cover will enable application of equations from Study 1 to estimate how cover differences affect sublimation and evaporation from the snow pack. For comparative purposes, snow vaporization from plastic film vessels will also be made. The interception of snow and its subsequent disposition will

be studied by the weighing of trees and by the exposure of ice cones within the forest canopy.

3. Snow sublimation and evaporation as affected by forest management: From Studies 1 and 2, hypotheses will be developed as to the forest manipulation that will minimize vapor loss from snow for different topographic situations. Plots will be the units of study. The continuing investigations of harvesting methods in mature lodgepole pine, mature spruce-fir, and of thinning methods in young lodgepole pine are part of this general study.

4. Solar radiation as affected by topography and forest: This will be a study of solar radiation absorbed by the snowpack as such absorption is affected by position with respect to topography and forest components, and by age of the snow surface. It will make full use of currently available or calculable information on variation of incident radiation with time of year and day and topographic slope and aspect. It will supplement this information by Horizontoscope measurements to pin-point magnitudes and periods of incident radiation. Changing albedo of the snow and the effect of the forest by its conversion of short-wave to long-wave radiation will be evaluated by a net radiometer.

5. Snowmelt as affected by forest management: From Study 4, hypotheses will be derived as to the type, pattern, and height of forest that will minimize rates of snowmelt on representative slopes and aspects. This study will test

these hypotheses on plots. Also tested will be hypotheses on how melt rates may be maximized and earlier melting induced. Knowledge from these latter tests will be of value in managing watersheds to reduce peak runoff by getting earlier runoff and may also enable getting greater water yield if studies of snow evaporation show that prolonged melting favors greater evaporation loss.

6. <u>Evapo-transpiration from soil as affected by forest type and treatment</u>: A study of this factor by the Fort Collins Research Center may or may not be necessary, depending on whether results elsewhere are adequate to answer questions involved. If inadequate elsewhere, then studies on a plot basis should be undertaken. Since this study will necessarily include the effects of rainfall interception, no separate investigation of this factor is required.

7. <u>Pilot plant study of water yield</u>: Watersheds will be used to test the plot results on how water yields may be maximized through reducing snow sublimation and evaporation and soil moisture losses through evapo-transpiration. It is probable that several watersheds will be needed in order to include the variability associated with topography. In this and other watershed studies, sediment discharges should be measured to see that tested practices do not increase erosion hazards significantly.

   The current investigation on Fool and East St. Louis Creeks and that on Red Sandstone Creek fall into this study. The currently gaged watersheds of Deadhorse and Lexen Creeks may be used for this study, or may be used for Study 8.

8. Pilot plant study of seasonal distribution of streamflow: The results of study 5, if of positive significance, will be tested on enough watersheds to include topographic variaton. Since the prolongation of snowmelt and high streamflow is probably of greater general value, tests of practices favorable to these goals will be first tested. Tests of methods to advance snowmelt and increase its rate on portions of watersheds in order to reduce peak flows and possibly increase total yield may be made later.

9. Plot study of combined water, timber, and recreational values: The preceding studies may show that management for maximum water values are incompatible with management for maximum timber and recreation values. If so, then a plot study will be made to determine points of compromise. The continuing studies of harvesting methods in mature lodgepole pine, mature spruce-fir, and of thinning methods in young lodgepole pine may be considered part of this study as well as part of study 3.

10. Pilot plant study of combined water, timber, and recreational values: Watersheds will be used to test the plot results of study 9.

11. Hydrologic characteristics of subalpine zone: Within the Fraser Experimental Forest and elsewhere as opportunity allows, geographic and topographic sampling will be done of annual precipitation, rainfall intensity, streamflow,

wind speed and direction, air temperature and air vapor pressure. Observations made by other agencies will be used to the fullest extent possible. Regression analyses will be made to establish relations between the hydrologic factors and elevation in order to allow extrapolation to non-sampled areas. Other parameters of topography and geography may also be used as preliminary analyses dictate. The past and current observations on the Fraser Experimental Forest of air temperature, wind speed and direction, annual precipitation, and rainfall intensity fit into this study. Data from existing stream gages will also be used to reveal influences of elevation on streamflow.

COOPERATION

The high value to water users of watershed management within the subalpine zone, as indicated by past research, suggests that eager cooperation by one or more of the following agencies can be expected:

1. Denver Board of Water Commissioners.
2. State of Colorado, Water Conservation Board.
3. U. S. Bureau of Reclamation.
4. Colorado River Water Users Association.
5. Colorado Watershed Conservation Association.

LITERATURE CITED

1. Bates, C. G., and Henry A. J.

    1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. Monthly Weather Review, Supp. No. 30.

2. Brown, H. E., and Dunford, E. G.

    1956. Streamflow in relation to extent of forest cover in central Colorado. Rocky Mtn. Forest and Range Expt. Sta. Paper No. 24.

3. U. S. Army, Corps of Engineers

    1955. Lysimeter studies of snowmelt. Res. Note No. 25, Corps of Eng., Dept. of the Army, Portland, Ore.

4. U.S.F.S., U.S.D.A., and Bureau of Reclamation, U. S. Dept. of the Interior.

    1951. Progress in snowmelt investigations at the Fraser Experimental Forest. Rept. No. 2.

5. Goodell, B. C.

    1952. Watershed management aspects of thinned young lodgepole pine stands. Jour. Forestry, 50(5).

6. Johnson, E. A., and Kovner, J. L.

    1956. Effect on streamflow of cutting a forest understory. Forest Science, Vol. 2(2).

7. Kittredge, Joseph

    1953. Influences of forests on snow in the ponderosa-sugar pine-fir zone of the central Sierra Nevada. Hilgardia,Vol.22(

8. Lieberman, J. A., and Hoover, M. D.

1951. Streamflow changes on Coweeta experimental watersheds. Trans. Amer. Geophys. Union, Vol. 32.

9. Love, L. D.

1955. The effect on streamflow of the killing of spruce and pine by the Engelmann spruce beetle. Trans. Amer. Geophys. Union, Vol. 36, No. 1.

10. ________

1953. Watershed management in the Colorado Rockies. Jour. Soil and Water Conservation, 8(3).

11. Miller, David H.

1955. Snow cover and climate in the Sierra Nevada, California. Univ. of Calif. Pub. in Geog., Vol. 11.

12. Rosa, J. M.

1956. Forest snowmelt and spring floods. Jour. Forestry, 50(4).

13. Wilm, H. G., and Dunford, E. G.

1948. Effect of timber cutting on water available for streamflow from a lodgepole pine forest. U.S.D.A. Tech. Bul. 968.